THE ORIGIN OF VERA RUBIN RIDGE: OVERVIEW AND RESULTS FROM CURIOSITY'S EXPLORATION CAMPAIGN. A. A. Fraeman[1], L. A. Edgar[2], E. B. Rampe[3], J. L'Haridon[4], N. Mangold[4], L. Thompson[5], J. Frydenvang[6], C. M. Fedo[7], J. P. Grotzinger[8], J. G. Catalano[9], V. Z. Sun[1], C. H. House[10], C. Hardgrove[11], T. S. J. Gabriel[11], S. Czarnecki[11], A. R. Vasavada[1], R. V. Morris[3], R. E. Arvidson[9], A. Bryk[12], S. Banham[13], K. Bennett[2], J. C. Bridges[14], W. E. Dietrich[12], C. S. Edwards[15], W. W. Fischer[8], V. K. Fox[8], S. Gupta[13], B. Horgan[16], S. Jacob[11], J. R. Johnson[17], S. S. Johnson[18], D. M. Rubin[19], M. Salvatore[15], S. P. Schwenzer[20], K. L. Siebach[21], N. T. Stein[8], K. M. Stack[1], S. Turner[20], D. Wellington[11], R. C. Wiens[22], A. Williams[23] [1]Jet Propulsion Laboratory, California Institute of Technology (afraeman@jpl.nasa.gov), [2]USGS Flagstaff, [3]NASA Johnson Space Center, [4]LPG, CNRS, Univ Nantes, [5]Univ. New Brunswick, [6]Univ. Copenhagen, [7]Univ. of Tennessee, [8]California Institute of Technology, [9]Washington University in St. Louis, [10]Pennsylvania State Univ., [11]Arizona State Univ., [12]U.C. Berkeley, [13]Imperial College London, [14]University of Leicester, [15]Northern Arizona Univ., [16]Purdue Univ., [17]Johns Hopkins Applied Phys. Lab., [18]Georgetown Univ., [19]UC Santa Cruz., [20]The Open Univ., [21]Rice Univ., [22]LANL, [23]Univ. of Florida

Introduction: In September 2017, the Mars Science Laboratory *Curiosity* ascended a layered ridge on the northwest flank of Aeolis Mons (informally known as "Mt. Sharp") (Fig. 1). The feature was called "Vera Rubin ridge" (VRR) to honor the pioneering American astronomer Vera Cooper Rubin (1928 – 2016).

VRR is one of several geomorphic features of Mt. Sharp that had been recognized in orbiter images and spectroscopic data before *Curiosity's* arrival in Gale crater [1-4]. In addition to being identifiable by its elevated topography, the ridge is composed of rocks that are texturally distinct compared with surrounding strata. In addition, VRR is associated with a strong spectral signature of crystalline red hematite in orbital data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM; Fig. 1).

Based on these orbital observations, VRR was originally interpreted to be an isolated hematite-bearing sedimentary interval within Mt. Sharp that marked a redox interface [3]. However, once *Curiosity* found hematite in seven of the nine drilled samples from Mt. Sharp taken below VRR [5, 6], the key questions concerning VRR progressed from "Why are there distinct hematite-bearing interval in Mt. Sharp?" to "How does the hematite in VRR relate to units stratigraphically below?" and "Why is the orbital spectral signature of hematite so strong at VRR compared with the underlying strata?"

Curiosity spent more than an Earth year exploring VRR, collecting detailed textural and compositional information that gave new insight into the ridge's origin and evolution, its relationship with the surrounding terrain, and the source of the orbital hematite signature. We will provide an overview of *Curiosity's* scientific campaign at VRR and synthesize high-level science results.

High-level summary of findings: Rocks comprising VRR are predominantly composed of fine-grained, thinly laminated parallel stratified bedrock that have approximately horizontal dips, consistent with deposition in lacustrine and lacustrine-margin settings that had occasional fluvial intervals [5, 6]. Rocks within VRR are classified as belonging to the Murray formation, and divide into the "Pettegrove Point" (lower) and "Jura" (upper) members [5]. Portions of the Jura member of VRR are also observed in "Glen Torridon" or the "clay unit" [5, 6].

VRR has a strong hematite spectral signature from orbit in part because there is less sand and dust obscuring the ridge rocks, but predominantly because there are deeper hematite spectral absorptions inherent to the VRR bedrock [7]. These deeper hematite absorptions are likely due to changes in grain size, amount of pigmenting hematite particles, and/or composition of additional ferric phases and amorphous materials, but do not reflect major changes in bulk hematite abundance [7,8]. Red hematite is dispersed throughout almost all of VRR, although there are ~ dozen meter to decameter-scale patches of gray bedrock concentrated in the Jura member [7,8].

Rocks in the VRR have similar major element compositions as underlying Murray formation strata, excluding the Marias Pass locality [9,10]. VRR is not enriched in FeO_T compared with underlying bedrock, except for some small diagenetic features that are nearly 100% FeO_T, likely Fe_2O_3, predominantly in the gray bedrock areas [11,12]. Although not enriched in iron, the variability of FeO_T across VRR is similar to that observed in hundreds of meters of rock below the ridge [9,10,13]. Neutron spectrometer data show an increased and variable bulk neutron absorption cross section in the Jura that is consistent with changes in Cl content, especially considering Fe variability is low in the member [9,10].

Three drilled samples from VRR were selected as representative samples to investigate the diversity of VRR rocks. All three samples contain feldspars, pyroxene, hematite, calcium sulfates, phyllosilicates, and X-ray amorphous material [14]. The sample from the gray bedrock contained hematite, and this was interpreted to indicate that gray hematite (>5 micrometer grain size) was present in the gray patches [14]. The phyllosilicate is Fe-rich [14, 15]. EGA analyses show trace and/or amorphous reduced sulfur species may also be present in the two samples from the Jura member, but at abundances below the XRD detection limit [16]. All three VRR samples contained trace chloride salts, and one sample had the first evidence for oxychlorine and nitrate salts since the Buckskin sample [15].

The origin of VRR: VRR forms a ridge because it is stronger (as evidenced in resistance to drilling) and more resistant to erosion than surrounding terrain. The induration of sedimentary rocks is primarily affected by compaction and cementation, which is in turn linked to porosity and permeability. *Curiosity* data show evidence for only small changes in grain size on VRR [12], so increased cementation contributes to VRR's relative erosion resistance. The composition of the cement is unconstrained, but it has been hypothesized to be hematite, calcium sulfate, phyllosilicates, and/or amorphous silica [14,17].

Curiosity data permit us to reject hypotheses that VRR formed at a redox interface because we do not see a substantial increase in total iron or abundance of ferric materials [3]. The ridge is also not an area of extensive, top-down oxidative weathering because there is not a higher concentration of iron oxides or high CIA values [9]. Variations in hematite spectral signatures cross-cut depositional boundaries [7,8], indicating that VRR is not depositional in nature, such as from an oxidizing interval in a redox-stratified lake. It is possible that a ferric or mixed ferrous/ferric precursor, such as green rust or ferrihydrite, did precipitate directly in the Gale lake [18], but later overprinting by one or more diagenetic events recrystallized or even mobilized iron-rich phases to create the observed cross-cutting feature. Most likely, the hematite or other iron oxide precursors observed on VRR and the rest of the Murray formation precipitated as a cement.

Portions of the Jura member of VRR are stratigraphically equivalent to Glen Torridon [5,6], which is expressed in a shallow wind-eroded trough upslope of VRR, so the geologic processes that differentiated their textural, topographic, and spectral properties occurred after both were deposited. Small and large-scale diagenetic features are abundant across VRR, which demonstrates that episode(s) of post-depositional water-rock interaction(s) affected the area [8,11,12].

We conclude that VRR is rocks that were locally hardened by due to diagenetic cementation, and subsequently differentiated from surrounding terrain by erosion. Diagenetic processes also created the uniquely deep ferric spectral absorptions that distinguish the ridge from orbit. The lack of large bulk chemical changes at VRR constrains the chemistry of the fluids that differentiated the ridge from the surrounding Murray. It is not possible to uniquely constrain a single geochemical model for the origin of VRR without detailed microanalysis, but several hypotheses have been proposed [9-11, 13-16, 19].

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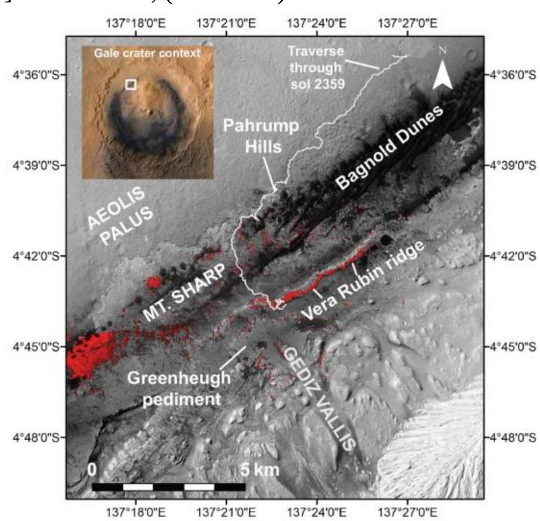

Fig. 1: Overview of Curiosity's traverse through sol 2359 (white line) over mosaic of CTX images showing the north-west quadrant of Mt. Sharp. Red areas show CRISM hematite detections (860 nm band depth map).